Engineering Failure Analysis 30 (2013) 1–9

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Forensic assessment of a bridge downfall using Bayesian networks

Milan Holický, Jana Marková, Miroslav Sýkora *

Czech Technical University in Prague, Klokner Institute, Solinova 7, 166 08 Prague, Czech Republic

ARTICLE INFO

Article history:
Received 12 July 2012
Received in revised form 29 November 2012
Accepted 8 December 2012
Available online 5 January 2013

Keywords:
Bridge failures
Failure analysis
Forensic engineering
Probabilistic risk assessment

ABSTRACT

Bayesian networks proved to be a useful tool in many technical fields as well as in forensic sciences. The present paper proposes a novel application of Bayesian networks in forensic engineering, focusing on the analysis of technical causes of a catastrophic bridge downfall. During repair a road bridge over important railway lines suddenly slipped down from temporary supports. Incidentally at the same time an intercity train approached the location and crashed into the collapsed bridge at a high speed. The accident resulted in great societal and economic consequences. Forensic investigation concerning causes of the bridge collapse was complicated due to the additional damage caused by the train. Moreover, the remaining structural elements of the collapsed bridge and temporary supports were shortly after the accident removed to renew railway traffic. Background materials of the investigation and additional detailed structural analyses did not reveal any convincing evidence of the initiation cause. Critical consideration of all possible causes including aerodynamic effects supplemented by a causal (Bayesian) network finally resulted in identification of the most significant causes including insufficient foundation and overall stiffness of temporary supports.

1. Introduction

1.1. Bayesian networks in forensic science and engineering

Evidence available for forensic engineering assessments may be considerably complex and scattered, covering information from different technical fields, combinations of numerical investigations, qualitative expert judgments, etc. Consequently, the complexity of evidence complicates identification of technical causes and formulation of required inferences. Probability theory, implemented through Bayesian networks, offers a powerful tool to deal with this complexity and discover valid patterns in the data [16].

Similar networks were firstly used to analyse trial evidence in 1913. Later various path diagrams were developed and applied in social sciences. The term "Bayesian networks" was introduced by Judea Pearl [12], regarding that:

- Available information is often subjective.
- Information updating is based on Bayes' theorem.
- Causal and evidential modes of reasoning are distinguished, referring to Thomas Bayes' paper from 1763.

* Corresponding author. Tel.: +420 2 2435 3850; fax: +420 2 2435 5232.
E-mail addresses: milan.holicky@klok.cvut.cz (M. Holický), jana.markova@klok.cvut.cz (J. Marková), miroslav.sykora@klok.cvut.cz (M. Sýkora).

1350-6307/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engfailanal.2012.12.014

In 1980s the properties of Bayesian networks were summarised in [11,9].

Recently, methods of formal reasoning have been proposed to assist forensic experts to understand dependencies which may exist among different aspects of the evidence. Bayesian networks can be a useful tool in forensic assessments since humans often fail to follow a logical framework in complex situations [4]. They represent mathematically and statistically rigorous techniques for handling uncertainty.

1.2. Motivation for the case study

The present case study is focused on the application of Bayesian networks in the assessment of technical causes of a recent catastrophic downfall of a composite steel–concrete road bridge.

The bridge over an important railway was built in 1950s. The three-span bridge consisted of a skew concrete slab on steel girders. In 2008 the bridge was under essential repair that was severely constrained by requirements on unrestricted railway traffic. The concrete deck located outside the railway track was removed and the bridge was partly pulled out of the track. The middle part of the deck was then demolished and re-concreted outside the track (see the upper part of Fig. 1). During the first steps of backward traction, the bridge suddenly slipped down from temporary supports on the track (positions of supports are illustrated in the lower part of Fig. 1). Incidentally at the same time an intercity train passed through the site and crashed into the collapsed bridge at a high speed (see Fig. 2). The accident resulted in eight fatalities, more than 90 injuries and considerable economic consequences. Immediately after the accident two civil engineers were charged for a public negligence.

The additional damage of the bridge due to the train impact (Fig. 2) significantly complicated forensic investigation of the collapse causes. Moreover, the remaining structural components of the collapsed bridge and temporary supports were shortly after the accident removed to renew the railway traffic.

In the beginning common methods of structural analysis were applied to analyse the collapse. It was found out that the resistance of temporary supporting structures was nearly exhausted in some phases of the repair, but still fulfilling the requirements of present codes. An initiating cause might have been estimated by comparison of several critical situations. However, lack of geodetical measurements and uncertain vertical positions of temporary supports on inappropriate foundations complicated estimation of effects of geometric deviations. Moreover, lack of anchoring and bracing of the temporary supports increased vulnerability of the structural system.

That is why probabilistic analysis [14] was accepted as an appropriate tool for forensic investigation due to irreducible uncertainties related to pre-collapse conditions (geometry, effects of passing high-speed passenger and heavy freight trains, activation of temporary supports by hydraulic jacks just before the collapse, etc.). In this context Bayesian networks were used in order to:

- Take into account quantitative description of expert judgements based on miscellaneous background information.
- Transparently illustrate various kinds of deficiencies during the construction, aerodynamic effects of passing trains and relationships among them.

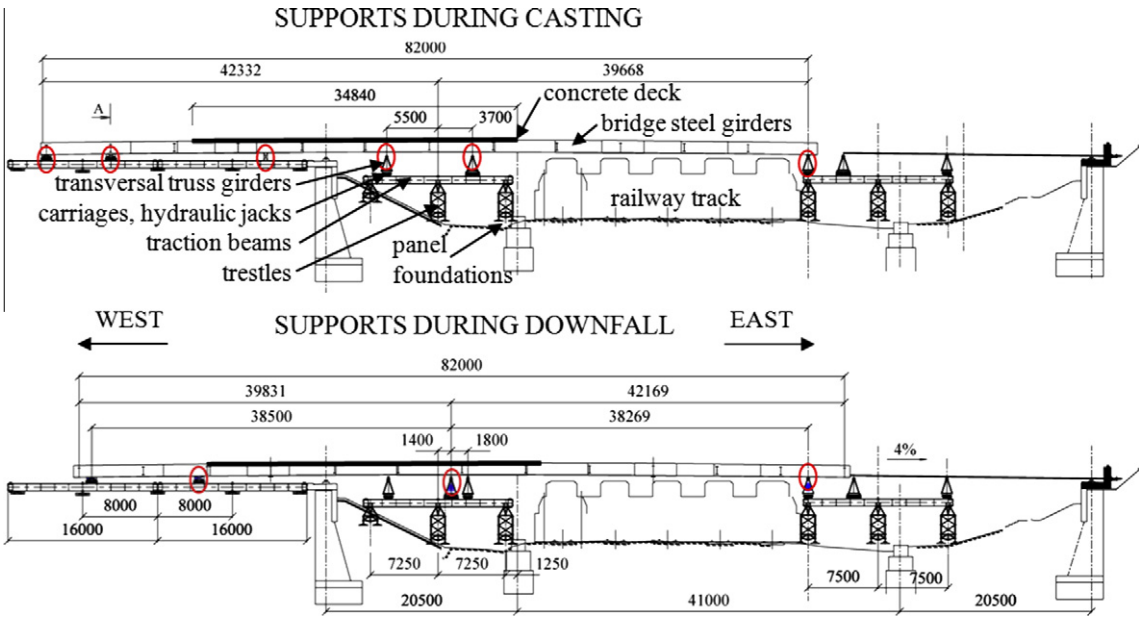

Fig. 1. Main components of the bridge and temporary structures, position of supports of the bridge during the repair and downfall (dimensions in mm).